A finite element model of seat cushion indentation with a soft tissue human occupant model

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Abstract

Effective digital human model (DHM) simulation of automotive driver packaging ergonomics, safety and comfort depends on accurate modelling of occupant posture, which is strongly related to the mechanical interaction between human body soft tissue and flexible seat components. This paper presents a finite-element study simulating the deflection of seat cushion foam and supportive seat structures, as well as human buttock and thigh soft tissue when seated.

The three-dimensional data used for modelling thigh and buttock geometry were taken on one 95th percentile male subject, representing the bivariate percentiles of the combined hip breadth (seated) and buttock-to-knee length distributions of a selected Australian and US population. A thigh-buttock surface shell based on this data was generated for the analytic model.

A 6mm neoprene layer was offset from the shell to account for the compression of body tissue expected through sitting in a seat. The thigh-buttock model is therefore made of two layers, covering thin to moderate thigh and buttock proportions, but not more fleshy sizes. To replicate the effects of skin and fat, the neoprene rubber layer was modelled as a hyperelastic material with viscoelastic behaviour in a Neo-Hookean material model. Finite element (FE) analysis was performed in ANSYS V13 WB (Canonsburg, USA). It is hypothesized that the presented FE simulation delivers a valid result, compared to a standard SAE physical test and the real phenomenon of human-seat indentation.

The analytical model is based on the CAD assembly of a Ford Territory seat. The optimized seat frame, suspension and foam pad CAD data were transformed and meshed into FE models and indented by the two layer, soft surface human FE model. Converging results with the least computational effort were achieved for a bonded connection between cushion and seat base as well as cushion and suspension, no separation between neoprene and indenter shell and a frictional connection between cushion pad and neoprene. The result is compared to a previous simulation of an indentation with a hard shell human finite-element model of equal geometry, and to the physical indentation result, which is approached with very high fidelity.

We conclude that

(a) SAE composite buttock form indentation of a suspended seat cushion can be validly simulated in a FE model of merely similar geometry, but using a two-layer hard/soft structure.

(b) Human-seat indentation of a suspended seat cushion can be validly simulated with a simplified human buttock-thigh model for a selected anthropomorphism.

Keywords: Automotive Seat, Seat Comfort, Cushion Deflection, Finite Element Model, Digital Human Model.

1. Introduction

Effective digital human model (DHM) simulation of automotive driver packaging ergonomics, safety and comfort depends on accurate modelling of occupant posture, which is strongly related to the mechanical interaction between human body soft tissue and flexible seat components. Both seat safety functions and seat comfort are key attributes for designing a seat (Van Hoof et al, 2004). As a physical seat design validation method, SAE J826 (Society of Automotive Engineers, 2008) is the widely accepted standard in the automotive

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industry. The method has proven to validly measure seat deflection and consequently the human H-Point for modern seats; however it lacks the capability to predict seat pressure with reasonable precision and confidence (Reed et al, 1999). Pressure mapping is the standard method for investigating static comfort (Andreoni et al, 2002; Siefert et al, 2008) at the seat body interface. The method however has not always proven practical in the past. While Kyung and Nussbaum (2008) reported correlations between aggregated driver–seat interface pressure factors and overall comfort ratings, Gyi and Porter (1999) and Porter et al (2003) found no consistent association between interface pressure and driving discomfort. This was partially supported by Paul et al (2012a), who found found that seat interface pressure measurements face reliability issues.

It is paramount for vehicle safety systems' performance that their analytic design involves reliable and valid DHM tools. The same applies for comfort oriented human models. In general, finite-element (FE) models have delivered useful results in previous simulations of passenger-seat interaction (Grujicic et al, 2009; Konosu, 2003; Murakami et al, 2004), even though some models assumed simplified linear tissue characteristics (Hartung et al, 2004; Mergl et al, 2004; Verver et al, 2004).

However thigh deformation is more significant than foam deformation for larger forces (Mills, 2007) and needs to be more carefully considered in modelling. Given a large inter-subject variability of muscle anatomy (Viceconti, 2003), current models represent rather subject specific human properties, than a generalized thigh and pelvis. In addition to soft tissue material parameters, the geometric shape of thighs and buttocks need to be considered in analytical models (Verver et al, 2005).

While a FE model with a rigid, human shaped indenter developed by Paul et al (2012b) was able to predict pressure distribution reasonably well, it showed a 12% error when simulating seat deflection in a spring suspended seat.

2. Materials and Methods

2.1. Seat and shell analytical models

Seat physical indentation for validation of analytical models was measured according to Ford engineering specification CETP 01.10-L-401. Both protocol and results of these measurements, as well as the physical seat specification were reported in Paul et al (2012b) (Fig 1).

An optimized analytical seat model was derived from the CAD assembly of a Ford Territory seat, representing seat frame, suspension and foam pad. The FE mesh of the seat CAD model was generated in ANSYS V13 WB (Canonsburg, USA).

Figure 1: Seat indentation test on an untrimmed seat cushion, following FORD CETP 01.10-L-401.

The three-dimensional indenter shell model of thighs and buttocks was generated from the scan of a 95th percentile male subject (Paul et al, 2012b).

A 6mm flexible material layer was offset from the rigid model to simulate a neoprene wrapping of the shell. This approach was to represent human soft tissue compression in the human-seat system, and the unknown non-rigid behavior of a composite material SAE J826 shell (Society of Automotive Engineers, 2008) in the physical model. Hence the thigh-buttock indenter model was made of two layers, a rigid steel and flexible neoprene layer representing lean proportions (Fig 2).

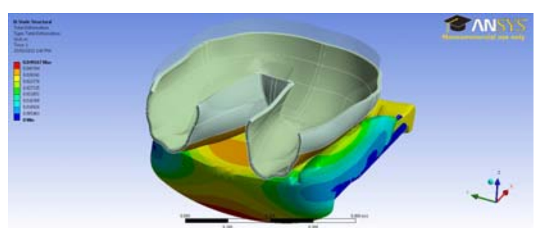

Figure 2: Two-layer, rigid steel and flexible skin (neoprene) indenter model in ANSYS V13.

2.2. Methods

To imitate the properties of skin and fat, the neoprene rubber layer was modeled as a hyperelastic material with viscoelastic behavior in a Neo-Hookean material model. The viscoelastic shear modulus of the material was 8.45 MPa. Finite element (FE) analysis was performed in ANSYS V13 WB (Canonsburg, USA). The new indenter shell was modeled using 1683 nodes and 1227 elements, while the neoprene wrapping of the shell was modeled with 1227 nodes and 1154 elements. Contact force was calculated using the penalty method (0.94 mm penetration) for a defined indenter stroke of 41mm.

3. Results

The presented revised FE simulation (model 2) delivered outcomes which are compared to the standardized physical test and previous simulation results using the rigid shell indentation BOB model (model 1; Paul et al, 2012b). The standardized physical test is considered a valid reproduction of the real phenomenon of human-seat indentation (Reed et al, 1999).

Converging results with the least computational effort were achieved for a bonded connection between cushion and seat base as well as cushion and suspension, no separation between neoprene and indenter shell and a frictional connection between cushion pad and neoprene. Results are compared with the previous simulation, using the anthropometrically equal BOB model (Paul et al, 2012b), and the physical indentation, which is approached with very high fidelity (Tab 1).

Young's modulus at contact was determined as 0.032 N/mm^2 (Fig 3), cushion elastic strain was 42% and maximum equivalent stress 1.41 MPa.

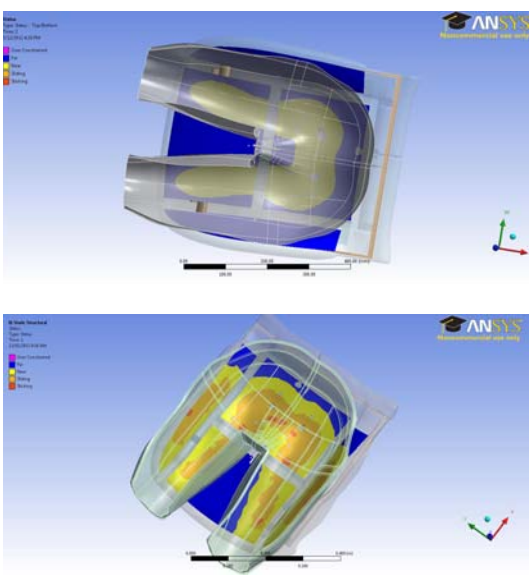

Figure 3: Simulated contact status at full indentation with model 1 (rigid, top) vs. model 2 (flexible, bottom).

Indentation in the simulation was performed in one second, while the physical experiment extended over 16.7 seconds.

Table 1: Physical vs. analytical parameters for 41 mm stroke at SgRP. All values reported are maximum values. Model 2: two layer shell indenter model.

	Physical untrimmed test	Model 2 simulation
Force [N]	922	957
Cushion mass [kg]	0.89	19.1*
Shell mass [kg] FORD CETP	8.6	8 (incl. Neoprene)
BOB in CAD		9.5
SAE J826	<10	

* This physical property was incorrectly reported by ANSYS V13 WB.

Compared to the forces for indentation (Tab 1), the mass of human thigh and upper body would be 96.5% (Dempster, 1961) of the mass of a 95th percentile (stature) Australian male (Peoplesize, Open Ergonomics Ltd, UK), which equates to 73.3kg (5th percentile)-111kg (95th percentile). As a consequence of a soft surface, the simulated contact pressure distribution is significantly more realistic in model 2 than in model 1 (Fig 4).

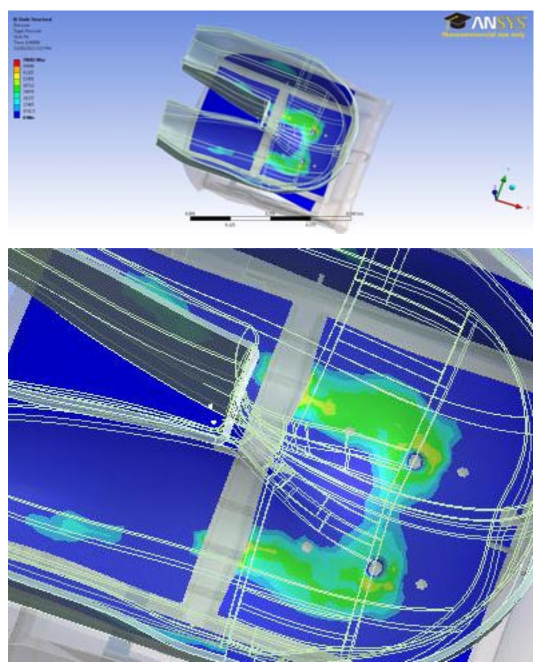

Figure 4: Simulated seat interface pressure when indented with model 2 (flexible surface).

This is due to the now conforming shape of the indenter, reflecting human soft tissue behavior. In a qualitative assessment, the simulated pressure distribution compares well with a physical measurement using a Tekscan CONFORMat® system (Tekscan, South Boston, USA)(Fig 5).

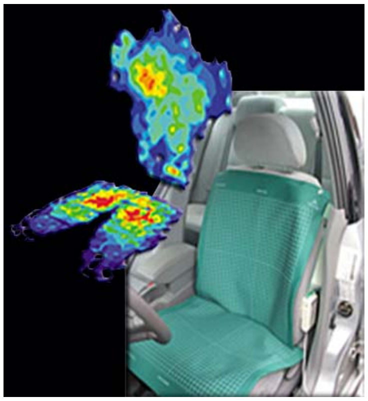

Figure 5: Seat interface pressure measured with Tekscan CONFORMat® (picture courtesy Tekscan).

4. Discussion

Results for Young's modulus (0.032 N/mm^2) at the contact interface and Poisson's ratio (0.42) compare well with the 3D-FE-model developed by Mergl et al. (2004), which uses in-vivo measurements and reports a Young's-modulus of E=0.03 N/mm^2 and Poisson's ratio of 0.49 for the posterior buttocks of a 50th percentile male. However it should be noted that the current BOB model only represents lean corpulence, and that the outer layer of the model would have to be further extruded for a more fleshy stoutness. Further on, the selected neoprene material properties may not suit such a model.

The two layer rigid-soft indenter model is able to reproduce the composite indenter behavior as used in SAE J826 and FORD CETP 01.10-L-401. This is particularly useful because the material properties of the SAE J826 indenter are unknown due to IP protection, and the composite indenter would likely be computationally more complex to simulate.

The indentation with the new model replicates physical indentation of a trimmed, suspended seat according to FORD CETP 01.10-L-401 with an error of 3.6%, which was not possible with the previously reported BOB model. The simulation result was achieved despite of the disparate indenter shapes.

The indentation speed for the simulation is realistic and reflects the true settling process. Hence the simulation goes beyond measuring a system property, which is the aim of the FORD test procedure.

Although the simulation model appears to predict a realistic pressure distribution, an analytic, numerical comparison of the simulated seat pressure distribution and the physical, measured pressure distribution will be required to fully validate the results.

5. Conclusion

We conclude that

(a) SAE composite buttock form indentation of a suspended seat cushion can be validly simulated in a FE model of merely similar geometry, but using a two-layer rigid and soft skin (neoprene) structure.

(b) Human-seat indentation of a suspended seat cushion can be validly simulated with a simplified human buttock-thigh model for a selected anthropomorphism.

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References

Andreoni G, Santambrogio GC, Rabuffetti M and Pedotti A, 2002. Method for the analysis of posture and interface pressure of car drivers. Applied Ergonomics, Vol. 33 (2002), pp.511–522.

Dempster WT, 1961. Free body diagrams as an approach to the mechanics of human posture and motion. In: Evans FG: Biomechanical studies of the musculo-skeletal system. Charles C Thomas.

Grujicic M, Pandurangan B, Arakere G, Bell WC, He T, and Xie X, 2009. Seat-cushion and soft-tissue material modeling and a finite element investigation of the seating comfort for passenger-vehicle occupants. Materials and Design, Vol. 30 (2009), pp.4273–4285.

Gyi DE, and Porter JM, 1999. Interface pressure and the prediction of car seat discomfort, Applied Ergonomics, Vol. 30 (1999), pp. 99-107.

Hartung J, Mergl C, Henneke C, Madrid-Dusik R, and Bubb H, 2004. Measuring Soft Tissue Compliance of the Human Thigh. SAE Technical Paper Series 2004-01-2158.

Konosu A, 2003. Development of a Biofidelic Human Pelvic FE-Model with Several Modifications onto a Commercial Use Model for Lateral Loading Conditions. SAE Technical Paper Series 2003-01-0163.

Kyung G, and Nussbaum MA, 2008. Driver sitting comfort and discomfort (part II): Relationships with and prediction from interface pressure. International Journal of Industrial Ergonomics, Vol. 38 (2008), pp.526–538.

Mergl C, Anton T, Madrid-Dusik R, Hartung J, Librandi A, and Bubb H, 2004. Development of a

3D Finite Element Model of Thigh and Pelvis. SAE Technical Paper Series 2004-01-2132.

Mills NJ, 2007. Polymer Foams Handbook: Engineering and Biomechanics Applications and Design Guide. Butterworth-Heinemann.

Murakami D, Kitagawa Y, Kobayashi S, Kent R, and Crandall J, 2004. Development and Validation of a Finite Element Model of a Vehicle. SAE Technical Paper Series 2004-01-0325.

Paul G, Daniell N, and Fraysse F, 2012a. Patterns of correlation between vehicle occupant seat pressure and anthropometry. WORK, Vol. 41(S1), pp. 2226-2231.

Paul G, Pendlebury J, and Miller J, 2012b. The contribution of seat components to seat hardness and the interface between human occupant and a driver seat. International Journal of Human Factors Modelling and Simulation (IJHFMS), Vol. 3, No. 3/4, pp.378-397.

Porter JM, Gyi DE, and Tait HA, 2003. Interface pressure data and the prediction of driver discomfort in road trials. Applied Ergonomics, Vol. 34 (2003), pp.207–214.

Reed MP, Roe RW, and Schneider LW, 1999. Design and development of the ASPECT manikin. Technical Paper 990963. *SAE Transactions: Journal of Passenger Cars, Vol. 108*.

Siefert A, Pankoke S, and Wölfel H-P, 2008. Virtual optimisation of car passenger seats: Simulation of static and dynamic effects on drivers' seating comfort. International Journal of Industrial Ergonomics, Vol. 38 (2008), pp.410–424.

Society of Automotive Engineers, 2008. SAE J 826 Devices for Use in Defining and Measuring Vehicle Seating Accommodation. SAE International.

Van Hoof J, van Markwijk R, and Verver M, 2004. Numerical Prediction of Seating Position in Car Seats. SAE Technical Paper Series 2004-01-2168.

Verver MM, van Hoof J, Oomens CWJ, Wismans JSHM, and Baaijens, FPT, 2004. A Finite Element Model of the Human Buttocks for Prediction of Seat Pressure Distributions. Computer Methods in Biomechanics and Biomedical Engineering, Vol. 7 No.4, pp.193-203.

Verver MM, de Lange R, van Hoof J, and Wismans JSHM, 2005. Aspects of seat modelling for seating comfort analysis. Applied Ergonomics, Vol. 36 (2005), pp.33–42.

Viceconti M, Ansaloni M, Baleani M, and Toni A, 2003. The muscle standardised femur. Journal of Biomechanics, Vol. 36 (2003), pp.145–146.